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CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

PROJECT SUMMARY REPORT
(a) Pressure Vessels Project
(b) Weld Process Development Project

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WELDING SECTION

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ENERGY RESEARCH PROGRAM

PHYSICAL METALLURGY RESEARCH LABORATORIES

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by

J.T. McGrath

ABSTRACT

Objectives, activities and outputs are summarized for the Pressure Vessels and Weld Process Development Projects.

LABORATOIRES DE RECHERCHE EN METALLURGIE PHYSIQUE
RAPPORT PRE/LRMP 83-87(TR)

RAPPORT D'UN RÉSUMÉ DE PROJET:
(a) Projet de baes sous pression
(b) projet de dévélopement de procédés de soudière

par

J.T. McGrath

RÉSUMÉ

Un résumé des objectifs, activités et rendements des bacs sous pression et des procédés de soudure.

PROJECT SUMMARY REPORT

(a) Pressure Vessels Project

1. INTRODUCTION

The Pressure Vessels Project, which commenced in the fiscal year 1979-80, has as its objectives, (a) the development and evaluation of pressure vessel fabrication and inspection technologies, and (b), the characterization and evaluation of properties of pressure vessel materials. The application of the scientific and technological outputs of the project are aimed primarily at the fabrication and in-service integrity of the large reactor vessels required for the hydrotreating of heavy oils and tar sands bitumen.

A market survey (see report listing), conducted under the auspices of CANMET in 1982, indicated the projected pressure vessel requirements for hydrotreating (upgrading) plants in Canada for a ten year period. Because of the present oil glut on the world market and the subsequent decline in the world price of oil, many of the proposed plans were shelved or cancelled. Despite this down turn in the market, there are several upgrading plants currently being planned by the Canadian Petroleum industry. Table 1 lists current Canadian upgrading plants that are either under construction or proposed for the near future. The Cold Lake and Wolfe Lake projects include only the production of bitumen and no upgrading at present. Upgrading of the bitumen from these two projects is being considered four or five years from now when the demand for asphalt material in the United States will reduce considerably.

This report summarizes the activities that have taken place in the project. Some of the project elements have been completed and final reports and papers describing the results are listed. Other work, particularly in the area of nondestructive evaluation is still underway. All the information generated in the project is available to Canadian industry to assist them in establishing fabrication and inspection technologies as well as in obtaining information on the in-service properties of pressure vessel materials.

2. PROJECT ACTIVITIES

The following project activities are listed under two headings, (a) Fabrication and Inspection Technology Development and (b), Properties of Pressure Vessel Materials.

2.1 Fabrication and Inspection Technology Development

1. Fabrication of pressure vessel nozzles.
   An evaluation of the electroslag casting technique for the fabrication of pressure vessel nozzles. Nozzles were prepared with 2.25 Cr - 1 Mo steel and the microstructure and strength and notch toughness properties were determined. Contract with Dr. A. Mitchell, Dept. of Metallurgy, University of British Columbia.

2. Welding of pressure vessel steels by the narrow-gap process.
   The research is examining the effect of weld process variables on the structure and properties of narrow-gap welds using the gas-metal-arc process with solid and flux-cored wires. C-Mn and Cr-Mo steels have been welded. Contract with Dr. E.M. Patchett, Dept. of Mineral Engineering, University of Alberta.

3. Strip-overlay process for pressure vessel lining.
   The work has covered the effect of process variables on bead geometry of submerged-arc strip-overlay welds and the metallurgical structure and mechanical properties of the overlay welds. Inhouse activity, Dr. R.S. Chandel, Mr. R.F. Orr.

4. Study of weld cracking in a 2.25 Cr-1Mo steel.
   Development of a predictive method for preventing hydrogen cracking in thick-section welds in 2.25 Cr-1Mo steel. Contract Mr. R. Lazor, the Welding Institute of Canada, Toronto.

5. NDE methods for characterizing defects in heavy sections.
   The objective of this work is to locate and size defects in heavy-section welds, using ultrasonic and radiographic techniques. Inhouse activity, Dr. D.K. Mak.

6. Automated ultrasonic testing system for characterization of defects in weldments. To design, develop and assemble an ultrasonic testing system capable of characterizing defects in weldments. Contract, Dr. M. Macecek, Techno-Scientific, Toronto.

7. Development of an online acoustic emission monitoring system. To develop an acoustic emission system capable of detecting defects during welding of thick-section pressure vessel steels. Contract, Dr. D.R. Hay, Mr. R. Chan, Tektrend International Inc., Montreal.

8. Power requirements for roll forming of heavy sections. Objective is to predict equipment capacity requirements to roll form Cr-Mo steel plate into cylindrical sections for pressure vessel fabrication. Inhouse activity, Dr. D.L. Baragar and Dr. J.J.M. Too.

2.2 Properties of Pressure Vessel Materials

1. Hydrogen embrittlement in stainless steel weld overlay. Effects of post-weld heat treatment and hydrogen on the tensile properties of weld overlay of types 316L and 347 stainless steel have been studied. Inhouse activity, Dr. W.R. Tyson.

2. Metallurgical factors affecting disbonding between stainless steel overlay and Cr/Mo base metal. The factors controlling disbonding have been studied in weld overlay/base metal test samples subjected to simulated service exposure. Inhouse activity, Dr. M.J. Godden.

3. Temper embrittlement in weld metals of Cr/Mo steels. The temper embrittlement of 2.25 Cr-1Mo welds prepared by various narrow-gap processes using a range of welding consumables is under investigation. Inhouse activity, Mr. R.F. Knight.

4. Phase transformations in weld overlay. Inhouse activity, Dr. J.D. Boyd, Dr. M.T. Shehata.

5. Materials and design for resistance to creep-crack growth.
   To assess the applicability of fracture mechanics methodology to the control of creep-crack growth in pressure vessels operating at high temperatures and pressures. Contract with Dr. D.S. Wilkinson, McMaster University, Hamilton.

3. PROJECT OUTPUTS

The following is a list of reports and papers that describe the current output of the research activities listed in section 2.

1. The fabrication of pressure vessel nozzles by ESC, A. Mitchell, Final Report DSS Contract OSU81-00149, 1983.
2. Narrow-gap welds using under-strength weld material, B.M. Patchett and D.G. Bellow, Proceedings of Conf. Welding in Energy Related Projects, WIC, Toronto, Sept., 1983.
3. Fabrication technology and material property requirements for heavy wall pressure vessels, J.T. McGrath, B.M. Patchett, W.R. Tyson, and R.F. Knight, CANMET Quarterly, V22, No.2, April-June 1983, p.279.
4. Submerged-arc strip-overlay welding of 2.25 Cr-1Mo steel, R.S. Chandel and R.F. Orr, Rep. ERP/PMRL 83-40(OP-J). Proc. Int. Conf. Welding in Energy Related Projects, WIC, Toronto, Sept.1983.
5. Effect of process variables on the bead geometry of the submerged-arc strip-overlay welds. R.S. Chandel and R.F. Orr, Rep. MRP/PMRL 83-45(OP-J), presented CIM Conf. Edmonton, Aug. 1983.
6. Study of weld cracking in 2.25 Cr-1Mo steel. R. Lazor. Final report available Jan. 1984.
7. Effects of post-weld heat treatment and hydrogen on types 316L and 347 weld overlay, W.R. Tyson, Rep. MRP/PMRL 83-30(J). Submitted for publication to Met. Trans., 1983.
8. Disbonding of stainless steel weld overlay following simulated pressure vessel service exposure, M.J. Godden, Rep. ERP/PMRL 83-69(TR).
9. Effects of rare earth additions to P-doped 2.25 Cr-1Mo steels, R.F. Knight, Rep. MRP/PMRL 83-15(TR).

10. Reduction of temper embrittlement of 2.25 Cr-1Mo steels by rare earth additions. R.F. Knight, W.R. Tyson, G. Sproule, Rep. ERP/PMRL 83-44(J). To be published in Metals Technology.
11. Temper Embrittlement of 2.25 Cr-1Mo steel, W. Tyson, Rep. MRP/PMRL 79-83(LS).
12. A quantitave metallographic study of the ferrite to sigma transformation in type 316 stainless steel. M.T. Shehata, M.J.A. Lavigne, J.D. Boyd. Proceedings of conf. microstructural science, Volume XI, 1983, p.89-99.
13. Validity of crack tip parameters in creeping solids. S.B. Biner, D. Watt and D.S. Wilkinson, ASME preprint 83-WA/PVP-10, 1983.
14. Market survey of pressure vessels for synthetic fuel production systems. Contract report by Chinook Fuel Innovations Ltd., Calgary, Alta. 1982.

4. HIGHLIGHTS OF PROJECT OUTPUTS

Some significant results of the pressure vessels project to date can be summarized as follows:

1. Electroslag casting of nozzles in 2.25 Cr-1Mo steel gives adequate mechanical properties after a normalize/quench/temper heat treatment. The process is cost-competitive with the conventional route of welding forged nozzles in nozzle sizes up to approximately 380 mm diameter. It becomes of economic advantage in the case of repetitive, multiple attachment of small nozzle sizes.
2. Narrow-gap welding processes offer a significant saving in weld metal volume with increased productivity for heavy-section steels in thicknesses $\geq$ 100 mm.
3. The results of submerged-arc strip overlay work have demonstrated that this process can deposit stainless steel overlays on 2.25 Cr-1Mo steel. It was found that to counter the dilution effects and carbon pick-up from the base metal a buffer layer of 309-L stainless steel was necessary. Nevertheless, the resulting deposits meet all ASME code requirements in both as-welded and stress-relieved conditions. In terms of productivity and quality of deposits, the submerged-arc strip-overlay process has an edge over conventional overlay processes.

4. The roles of carbon content, post-weld heat treatment and overlay thickness have been shown to be critical to the disbonding of stainless steel overlay for Cr/Mo base metal. In general, the minimum carbon content of overlay and base metal, the shortest time at the lowest temperature during post-weld heat treatment, and the thickest overlay layer tend to minimize disbonding.
5. The proportional relationship between the amount of temper embrittlement caused in 2.25 Cr-1Mo steel by a step-cooling treatment and the J-factor [(Mn+Si) x (P+Sn) x 10^4] was confirmed. Auger microscopy of intergranular fracture surfaces of embrittled steel confirmed that the embrittling species is phosphorus. Rare earth (RE) additions, at levels such that RE = 8.75 + 2.3 Sn + 4.5 P, resulted in a significant reduction in the degree of temper embrittlement as measured by the shift of impact transition temperature. Auger analysis confirmed the presence of phosphorus combined with RE in many of the non-metallic inclusions present. The large numbers of inclusions, even with vacuum-treatment, resulted from the large RE addition required by the high P content, and this, in turn, resulted in a significantly lower upper-shelf energy for the RE-bearing steel.

PROJECT SUMMARY REPORT
(b) Weld Process Development Project

1. INTRODUCTION

The principal aim of the Weld Process Development Project, which commenced in 1981, is to develop narrow-gap welding systems for the joining of heavy-section steels of thicknesses equal to and greater than 150 mm. The potential advantages of narrow-gap processes are: improved productivity, reduced welding costs, and improved notch toughness properties in the weld metal and heat-affected zone. Because the emphasis of the project is to develop in-shop heavy-section welding technology, the bulk of the project is being carried out under contract to the Canadian fabrication industry.

The prime application of the heavy-section welding technology is in the fabrication of the large, thick-walled steel pressure vessels required for upgrading of heavy oils and tar sands bitumen. Both the longitudinal and circumferential welds of the wall of the pressure vessel can be joined by narrow-gap welding.

Recent discussions with industry have indicated other heavy-section structure fabrications in which the use of narrow-gap welding would be technically and economically feasible. For example, the legs or racks of jack-up offshore structures are made of high-strength, thick-section steel (, 200 mm). The jack-up rigs may be used for offshore drilling and production in the East Coast Sable Island gas fields. Japanese fabricators are presently using the narrow-gap process to join rack sections, end to end, in jack-up rig fabrication.

The report describes the activities currently underway in the project. The reports generated in the project are available to Canadian industry to assist them in evaluating heavy-section welding systems, in general and more specifically, in the development of welding procedures for narrow-gap welding.

2. PROJECT ACTIVITIES

Most of the work listed below, has been devoted to the development of narrow-gap welding systems for the joining of heavy-section pressure vessel steels. This work is performed inhouse and under contract.

1. Evaluation of the structure and properties of heavy section-welds
   Welds are being prepared in pressure vessel steels (SA387Gr22, SA516Gr70) using the submerged-arc narrow-gap process with a Miller square wave AC power source. Weld procedures are being developed for a range of welding consumables. The microstructure and mechanical properties of the weld metal and heat-affected zone regions will be assessed. Inhouse laboratory scale activity, Dr. R. Chandel, Mr. R. Orr.
2. Narrow-gap welding process development.
   The in-shop capability for narrow gap welding is being developed. The commercial application of narrow-gap welding to the joining of pressure vessel steels in flat and cylindrical plate sections is being demonstrated. Contracts with (1) Babcock and Wilcox Canada, Mr. M. DiTommaso, Mr. B. Wright and (2) 97613 Canada (Joint Venture Co. of Victoria Machinery Depot and Chinook Fuel Innovations Ltd.), Mr. W. Kesel, Mr. P. Manuel, Mr. E. Dyke.

3. PROJECT OUTPUTS

The work performed to date in the project is described in the following reports and papers.

1. Submerged-arc narrow gap welding, R.S. Chandel, R.F. Orr and J. Gianetto, Rep. ERP/PMRL 83-41(TR).
2. Mechanical properties of 2.25 Cr-1Mo steel weld metal deposited by the submerged-arc narrow-gap process. R.S. Chandel, J.T. McGrath, R.F. Knight, R.F. Orr, submitted for presentation at CIM Annual Meeting, 1984.
3. Weld-process development for heavy-weld pressure vessels Phase I report, Babcock and Wilcox Canada, Mr. B. Wright, available Dec. 1983.
4. Weld-process development for heavy-wall pressure vessels, Phase I Report, 97613 Canada, Mr. P. Manuel, available January 1984.

4. AVAILABILITY OF PROJECT REPORTS

Anyone wishing to obtain copies of reports from the two projects reviewed in this report may do so by contacting:

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Table 1 - Proposed Canadian upgrading plants

Proposed upgrading plant	Capacity bbl/day	Feed Stock	Status
1. PetroCan/CANMET (Montreal)	5K	Refinery Resid (Startup 1985)	Under construction
2. Syncrude Expansion (Fort McMurray, Alberta)	40K	Bitumen	Under discussion (probable startup 86/87)
3. Cold Lake (Cold Lake, Alberta)	20K	Bitumen	Under discussion (probable startup 87/88)
4. Husky Oil (Lloydminister)	12K	Heavy Oil	Under discussion (probable startup 87/88)
5. Shell Oil (Scotsford, Alta.)	50K	Synthetic crude	Completed
6. Consumers Co-operative Refineries Ltd. (Saskatchewan)	50K	Heavy Oil	Start construction 1985 (probable startup 86/87)
7. Wolfe Lake (Alberta)	7K	Bitumen	Under discussion (probable startup 87/88)
8. Future Upgrading Pilot Plants	1 to 5K	Heavy Oil	Possible construction or demonstration 85/86